May 30, 2007

THOUGHT STARTER ON CALIFORNIA GREEN CHEMISTRY INITIATIVE

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For most of the last century, DuPont has been among the largest chemical producers, globally. Our 200 year heritage of leadership in workplace safety, toxicology, science and technology positioned us as a premier company in safely handling hazardous chemicals; and in innovation in chemicals that has delivered extraordinary value across society. Creation of nylon is perhaps most familiar, but that is but one example among the 34,000 patents to which DuPont's innovation has led.

TRANSITION TO SUSTAINABILITY: One of the more recent examples of DuPont innovation received a Presidential Green Chemistry Challenge Award. Such awards are always welcome recognition, but this one is a particularly significant example for the CalEPA initiative. The Award was for microbial production of 1,3-propanediol – a critical ingredient in production of an entire new polymer platform (DuPont Sorona). It is the first example of a highly engineered microorganism used to convert a renewable resource into a chemical at high volume. In this case, the use of this microbe allows replacement of a petroleum feedstock with corn, with additional benefits of reducing energy consumption in manufacturing as well as improving process safety. Commercial production of this polymer began last year.

This example is significant for the Green Chemistry Initiative in part because it is not "chemistry" as we have traditionally known it. Rather, it is the melding of chemistry with biology, with the aim of delivering a product that has broad value across society, but doing so in a way that is less dependant upon depleting resources, safer to manufacture, and more economical to produce than traditional alternatives – in short, that is more sustainable both environmentally and economically. DuPont has spent much of the past decade reshaping our business portfolio to position us as an agent of such "sustainable growth." Our transformation is certainly not yet complete, but it is noteworthy that it is well underway. Importantly, we are not alone in sensing and anticipating this as a broader societal transformation (a quick review of the other "Green Chemistry" award winners illustrates this).

Transition toward more sustainable practices that still deliver the goods and services that societies expect represents a paradigm-shift from industry's historic role as, in a sense, the "enabler" of mass society. The new paradigm frames a more complex expectation of industry as an enabler of long term, more sustainable well-being, with a new emphasis on social and environmental responsibility. California's Green Chemistry Initiative can position the State for leadership as this transition proceeds. It is important to keep in mind, however, that this transition is already underway, and ill-conceived state intervention can just as easily retard its progress and thus the potential for California leadership.

"GRAND CHALLENGES" FOR THE CHEMICAL INDUSTRY: The application of science and innovation to meet society's needs and solve its challenges has always been a significant contribution of industry, generally, and the chemical industry in particular. This role of the chemical industry is no less vital today, but the challenges differ, as does the societal expectation of how we will approach those challenges. The 2006 UC report on "Green Chemistry in California" made a useful contribution to framing that larger societal need. It pointed to a 2005 conference of the US National Academy of Sciences. The focus was on the "Grand Challenges and Research Needs" for the chemical industry in both becoming more sustainable as an industry, and enabling society as a whole to advance toward greater sustainability. These include advancing our understanding of **toxicology**, application of principles of **green and sustainable chemistry**, and extending the use and sophistication of the **life cycle analysis** integral to green chemistry. Importantly, this broad agenda of challenges for which the society is depending upon an agile and innovative chemical industry goes beyond the more narrow conceptions of "green chemistry." The "Grand Challenges" (to which California Initiative should contribute) also include:

- **Renewable Chemical Feedstocks**
- **Renewable Fuels**
- **Energy Intensity of Chemical Processing**
- **Separation, Sequestration and Utilization of Carbon Dioxide**
- **Sustainable Education**

As noted above, the transformation necessary to address these challenges has already begun. It is a product of the same broad evolution in societal expectations that is also driving the movement toward green chemistry, generally, and the California Green Chemistry Initiative, specifically.

"GREEN CHEMISTRY" AND CALIFORNIA: One of the benefits anticipated for the State from taking on leadership roles in sustainability issues such as climate change and green chemistry is that the State will become a nexus for answers to the World's sustainability challenges, with economic benefits in addition to the direct benefits deriving from more sustainable practices. The State is anticipating precisely such "innovation" leadership from its climate initiative, which poses significant economic implications for many of the manufacturing enterprises remaining in California. The State's future is now heavily dependant upon alternative fuels, advances in sustainable production and the like, that track very closely the "Grand Challenges" above. Importantly, industries innovating to meet such needs may, or may not, end up being based in California. In today's global economy, simply accelerating emergence of a market does not guarantee that innovation and production to feed that market will locate there. The migration of semiconductor fabrication out of California offers an interesting case in point.

One of the realities in green chemistry is that the "chemical industry" in California has changed in recent decades. Much of the primary chemical production has consolidated in other states and, in particular, migrated to China and elsewhere in the developing World. The dynamics for this are complex, but at its core are, again, realities of global economic competition. This exaggerates the impact of a wide range of factors of production, but the net is simply that the State is not "self-contained" in its efforts to advance notions of green chemistry.

The description of intent for the Green Chemistry Initiative certainly implies that regulatory outcomes are anticipated. In that context, both already-emerging efforts of industry to fashion more sustainable practices and the fact that many primary chemical producers are not in-State, argue for very careful consideration of any regulatory proposals. This is particularly the case where unilateral state initiatives are contemplated, which must ultimately nest within any larger national regulatory structure. Additionally, there is a the growing global regulatory structure created by treaties such as the Stockholm and Rotterdam Conventions, framing systematic international approaches to persistent toxins and emerging chemicals of concern. A strategically appropriate state regulatory framework would hopefully offer incentives that reward innovation that enhances sustainability – the kind that accelerates the evolution that has already begun within industry. Innovation, however, is not narrowly a function of regulation, and it is possible for ill-conceived regulatory approaches to inhibit innovation by being overly prescriptive. It is also possible to discourage in-State investment in the kinds of innovative R&D and manufacturing sought, by imposing regulatory burden beyond what is necessary, effectively penalizing even willing industry versus competitive opportunities in other states or countries.

PRINCIPLES OF GREEN CHEMISTRY: The "Principles of Green Chemistry" that evolved from the work of John Warner and Paul Anastes represent a challenge to the chemicals value-chain, beginning with the primary chemical producers, but extending downstream throughout the economy. These capture essential notions of the transition to sustainable growth, and are very appropriate as a point of reference in the Green Chemistry Initiative. However, the aim is integration of these more systematically into R&D and **design** of products, rather than the traditional focus of health and environmental regulations on appropriate **use** of products.

Such design questions relating to chemicals tend to be dominantly the product of corporate (and to a degree, academic) research that is often distant from any regulatory interface, beyond basic workplace safety considerations and laboratory standards. The challenge in advancing these principles is therefore one of stimulating education and awareness in these key bastions. It is important to note that these principles and their challenge are effectively calling for an acceleration of a process already under way. They capture essential notions of that should be integrated into product design, but do not exist in a vacuum. There are forces already at work (particularly in the US) to stimulate greater attention to these dimensions of product design. To understand this, it is useful to rearrange the 12 Principles. They actually fall into two basic categories – those aimed at minimizing "environmental footprint" (waste and resources consumption) and those aimed at reducing risk.

Minimize Environmental Footprint: Eight of the 12 Principles essentially argue for more explicit attention to pollution prevention and reducing resource consumption – in essence, lifecycle consideration of "environmental footprint." These concepts have been evolving for decades as areas of increasing focus within industry. The chemical industry has been at the forefront in application of lifecycle analysis. DuPont, for example, systematically applies such analyses in the context of internal product stewardship reviews. Reducing hazardous waste has been a major consideration ever since the "Love Canal" era. Likewise, the US Toxic Release Inventory begun in the early '90s focused industry attention on reducing waste, generally. The potential benefits of reducing energy and natural resource consumption has long been a major consideration in some industries, but the oil embargo's of the '70s broadened the number of industries viewing energy as a significant factor of production. In this larger context, the great contribution of the Green Chemistry Principles is to translate these broad drivers into very specific decision contexts of chemical design and engineering. This linkage has been taking root in many companies. The challenge is to broaden, deepen and accelerate that more explicit focus by applying the following principles:

- **Prevent waste**: Design chemical syntheses to prevent waste, leaving no waste to treat or cleanup.
- **Use catalysts, not stoichiometric reagents**: Minimize waste by using catalytic reactions. Catalysts are used in small amounts and can carry out a single reaction many times. They are preferable to stoichiometric reagents, which are used in excess and work only once.
- **Avoid chemical derivatives**: Avoid using blocking or protecting groups or any temporary modifications if possible. Derivatives use additional reagents and generate waste.
- **Maximize atom economy**: Design syntheses so that the final product contains the maximum proportion of the starting materials. There should be few, if any, wasted atoms.
- **Design chemicals and products to degrade after use**: Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.
- **Analyze in real time to prevent pollution**: Include in-process real-time monitoring and control during syntheses to minimize or eliminate the formation of byproducts.
- **Use renewable feedstocks**: Use raw materials and feedstocks that are renewable rather than depleting. Renewable feedstocks are often made from agricultural products or are the wastes of other processes; depleting feedstocks are made from fossil fuels (petroleum, natural gas, or coal) or are mined.
- **Increase energy efficiency**: Run chemical reactions at background or room temperature and pressure whenever possible.

Reduce Risk: Four of the 12 Principles are specifically directed at reducing risk associated with chemical products and their production. Here as well, attention has been evolving for decades, in significant part as a function of evolution in science, technology (esp. in detection limits) and our general understanding of chemical risk. Attention to this dimension of chemicals experienced a step-change with the adoption of the Toxic Substances Control Act (TSCA) in the US in 1979 (and similar laws in Europe and elsewhere). Development of the chemical industry's pioneering Responsible Care program and its various elements is a very visible and significant manifestation of the degree to which these risk considerations have been internalized within the industry. The role of direct government intervention and enforcement in advancing this focus varies. In the US, for example, the evolution of tort law over the past 40 years has added a dimension to demands for product stewardship that has been relatively independent of specific regulatory controls. That has not been the case in most of Europe, in contrast, with the result that in the EU the formal regulatory structure (e.g. REACH) therefore plays a relatively larger role. In both these contexts, though, the potential contribution of the Green Chemistry Principles is to translate these more general concerns into specific considerations in chemical design and engineering. As with the environmental footprint elements, there are varying degrees of awareness and integration of these principles among corporations and other significant R&D institutions. The challenge is to broaden, deepen and accelerate attention to the following principles.

- **Design safer chemicals and products**: Design chemical products to be fully effective, yet have little or no toxicity.
- **Design less hazardous chemical syntheses**: Design syntheses to use and generate substances with little or no toxicity to humans and the environment.
- **Use safer solvents and reaction conditions**: Avoid using solvents, separation agents, or other auxiliary chemicals. If these chemicals are necessary, use less harmful or dangerous chemicals.
- **Minimize the potential for accidents**: Design chemicals and their forms (solid, liquid, or gas) to minimize the potential for chemical accidents including explosions, fires, and releases to the environment.

CONCEPTUALIZING "GREEN CHEMISTRY" CHALLENGES: The UC Berkeley report on "Green Chemistry in California" implies a number of questions regarding the appropriateness and efficacy of current chemical practices and the larger regulatory framework within which those have evolved, particularly TSCA. It begins with expressions of concern over the volume and continued expansion of chemical production. That concern is misplaced. Chemicals are being used precisely because economic growth and well-being are being enabled by chemistry. Every chemical has unique properties. The challenge is to safely harness those properties in a way that adds value to the society. Importantly, many properties of chemicals that can be harnessed to benefit society can be hazardous and can create risk if they are not properly handled. Even chemicals with very low "hazard" can cause risk in certain conditions.

The challenge of chemistry in the society is to harness the potential benefits associated with proper use of chemicals without inordinate risk. Green Chemistry is still aimed at harnessing this potential and delivering the benefits of unique chemical attributes. The difference is in giving more explicit consideration to possible lifecycle environmental and health risk in the **design** of chemicals and chemical products. The UC report does not focus on the Green Chemistry Principles, but rather on what it describes as systemic gaps in data, safety and technology. In essence, it seems to argue that these "gaps" are preventing the US and California from realizing the full potential of Green Chemistry – from applying the Green Chemistry Principles along the value chain. A useful starting point for discussion under the California Green Chemistry Initiative might therefore be to consider those allegations and explore specific questions that logically follow from them:

Data Gap
- Is there a "Data Gap"?
  - TSCA Section 4, 5, 8 all funnel extensive data to EPA – is it used? Is it accessible where it needs to be accessible?
  - ACC/ICCA HPV programs delivered base-set data across very broad range of high production volume "existing chemicals" – is it being used? Is it accessible?
  - MSDS process is intended to provide basic guidance necessary to reduce risk – is it being used appropriately? Is it capturing necessary information? Is the information accessible (availability, language, etc.) where and when it is needed?
- What is systemically missing?
  - Where are the real opportunities to make a difference?

- **Safety Gap**
- Where is the Safety Gap?
  - Chemical manufacturing safety is very high compared to other manufacturing and non-manufacturing environments – what is that telling us about the ability to handle chemicals safely?
  - Examples of problems often involve small businesses
    - OSHA gap?
    - MSDS gap?
- What is systemically missing?
  - Where are the real opportunities to make a difference?

- **Technology Gap**
- Is there a Technology Gap? Is the US in danger of falling behind EU and other countries reforming their chemical programs?
  - Chemical industry → 12% of US patents – the chemical markets are in midst of evolutionary change – not clear that US is less adaptive
    - Chemical markets demanding "greener" products and "greener" outcomes
    - Chemical industry is responding to that market evolution
- What is systemically missing?
  - Where are the real opportunities to make a difference?